# CHAPTER 5

# AN EXAMINATION OF BENEFITS AND COSTS OF MOBILE SOURCE CONTROL CONSISTENT WITH ACHIEVEMENT OF AMBIENT STANDARDS IN THE SOUTH COAST AIR BASIN

## INTRODUCTION

Chapter 3 described an experiment conducted in the South Coast Air Basin to quantify and validate benefit measures of air quality improvements. The qualified success of that effort suggests that a policy application of those benefit measures may be appropriate. Thus, the intent of this chapter is to examine national ambient air quality standards in a benefit-cost analysis framework as applied to the South Coast Air Basin which consists of all or portions of Los Angeles, Orange, Riverside and San Bernardino Counties in Southern California.

The national ambient standards for oxidant (formerly .08 and now .12 ppm maximum hourly concentration) and nitrogen dioxide (.05 ppm annual average concentration) are consistently violated throughout the basin with the notable exception of the immediate coastal areas which we have described as characterized by "good" air quality in Chapter 4 [See Figures 3.13.4 in Brookshire, et al. (1978) for a map of air quality areas]. Thus, in a broad context, if the entire South Coast Air Basin were to be brought into compliance with ambient standards, areas we have characterized as having "fair" or "poor" air quality would then be characterized as having "good" air quality. The development of an aggregate benefit measure for achieving ambient standards for the entire basin is then a straightforward extrapolation (given the original experimental design) where benefits are taken to be the aggregate willingness to pay for all households in both "poor" and "fair" air quality areas to have "good" air quality, as defined both for the preceding property value and survey studies. Of course, any extrapolation to a basin-wide population of about 2.4 million households (homes) from a sample of 719 home sales or from interviews with about 400 households can come under serious question. In particular, the communities chosen for sampling, although characterized by considerable variation in income and social characteristics, may not represent a random sample of communities in the South Coast Air Basin. However, the property value study does allow calculation of household willingness to pay as a function of income and air pollution. It is this relationship that we use for benefit calculations assuming, in effect, that income and population affect willingness to pay for air quality improvement in the same way throughout the basin as they did in our limited sample. Note that these estimates exclude any agricultural or ecosystem effects.

Since benefits are calculated for moving from the current (1976 emissions inventory) level of air quality to the ambient standards, costs must be calculated on the 'same basis. However, our preliminary analysis indicated that costs for on-road mobile source control measures were substantially more defensible than those associated with stationary and institutional controls. Therefore only the benefits and costs attributable to on-road mobile source control are examined to the exclusion of other control measures.[2] Benefits are then those corresponding to the share of total emissions reductions which are accomplished by on-road mobile source control. Costs are calculated for only these measures also.

Although a careful engineering-cost study for using mobile source control to achieve ambient standards would be desirable, the objective here must be quite limited in that we are forced to use available cost evidence which in many cases is quite uncertain. For the most part, we have relied on manufacturer statements and government publications for cost calculations. In developing control cost estimates, given the large uncertainty which exists, we simply present available data on the range of costs per ton of reduced emissions for hydrocarbons, carbon monoxide and nitrogen oxides and, using these numbers, estimate a broad range for basin-wide control costs to compare to the range of benefit measures.

In addition, we have used the <u>Air Quality Management Plan</u> (January, 1979) as the basis for the calculation of required emissions reductions. Calculations presented in the plan indicate that to achieve ambient standards in 1979 would require reductions of 974 tons per day in reactive hydrocarbons, 5963 tons per day of carbon monoxide and 503 tons per day of nitrogen oxides. Of these amounts we have estimated that mobile source controls are responsible for 728 tons/day, 6023 tons/day and 397 tons/day of hydrocarbons, carbon monoxide and oxides of nitrogen, respectively. Our principle conclusions can then be summarized as follows:

> Benefits of achieving ambient standards for air quality in the South Coast Air Basin for 1979 fall in a range of 1.6 to 3.0 billion dollars per year. Of this total on-road mobile source control is responsible for approximately 1.36-2.55 billion dollars.

Assuming that to achieve the ambient standards in 1979 the on-road mobile source emission reductions are those stated above, then corresponding total basin-wide control costs fall in the range of .6. - 1.32 billion dollars.

Benefits of control efforts to achieve ambient air quality standards in the South Coast Air Basin appear to be of the same order of magnitude as control costs. Given uncertainties over benefits and costs, this implies that ambient air quality standards cannot be rejected as economically inefficient on the basis of benefit-cost analysis.

Continued growth of population and economic activity in the South Coast Air Basin could well alter the relative magnitudes of benefits and costs of achieving the ambient standard in an unknown direction by the attainment date of 1987.

The next section briefly discusses the use of this type of benefit-cost study in policy analysis. Section 3 describes the construction of aggregate benefits, costs of control are presented in Section 4, and Section 5 concludes with a comparison of benefits and costs.

## THE APPLICATION OF BENEFIT-COST ANALYSIS TO ENVIRONMENTAL STANDARDS

The application of benefit-cost analysis to environmental standards has been described in great detail in the economics literature (see for example Kneese and Herfindahl, 1974). An ideal or optimal standard is one where net benefits -- the difference between benefits of improved air quality and control costs -- are the greatest. For example, Figure 1 shows the optimal standard as $S_1$, where the degree of air pollution control provides a level of improved air quality (as measured on the horizontal axis) such that benefits, $B_1$, exceed control costs, $C_1$, (or both measured on the vertical axis) to the greatest extent. Note that in Figure 1, benefits are assumed to increase at a decreasing rate with air quality improvement while control costs are assumed to increase at an increasing rate. The slopes of these relationships are presumed to arise respectively from (i) the diminishing rate of increase of value to consumers of improved air quality as air quality approaches "perfection" and (ii) because costs of additional emissions control will rise increasingly rapidly as a level of zero emissions (i.e., perfect air quality) is approached. At the optimal or economically efficient standard, $S_1$, given our assumptions, benefits strictly exceed costs ($B_1 > C_1$). Thus, in evaluating the role that on-road mobile controls play in achievement of the national ambient air quality standards as applied in the South Coast Air

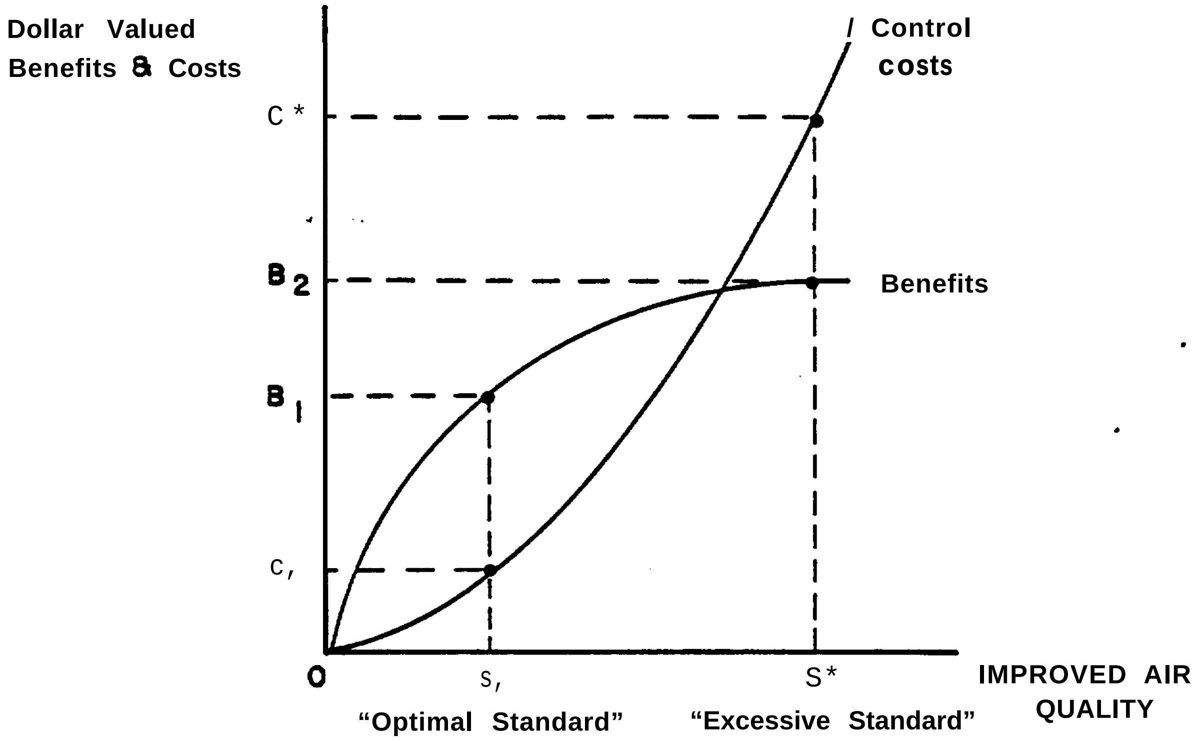



Figure 5.1
Optimal and Excessive Standards

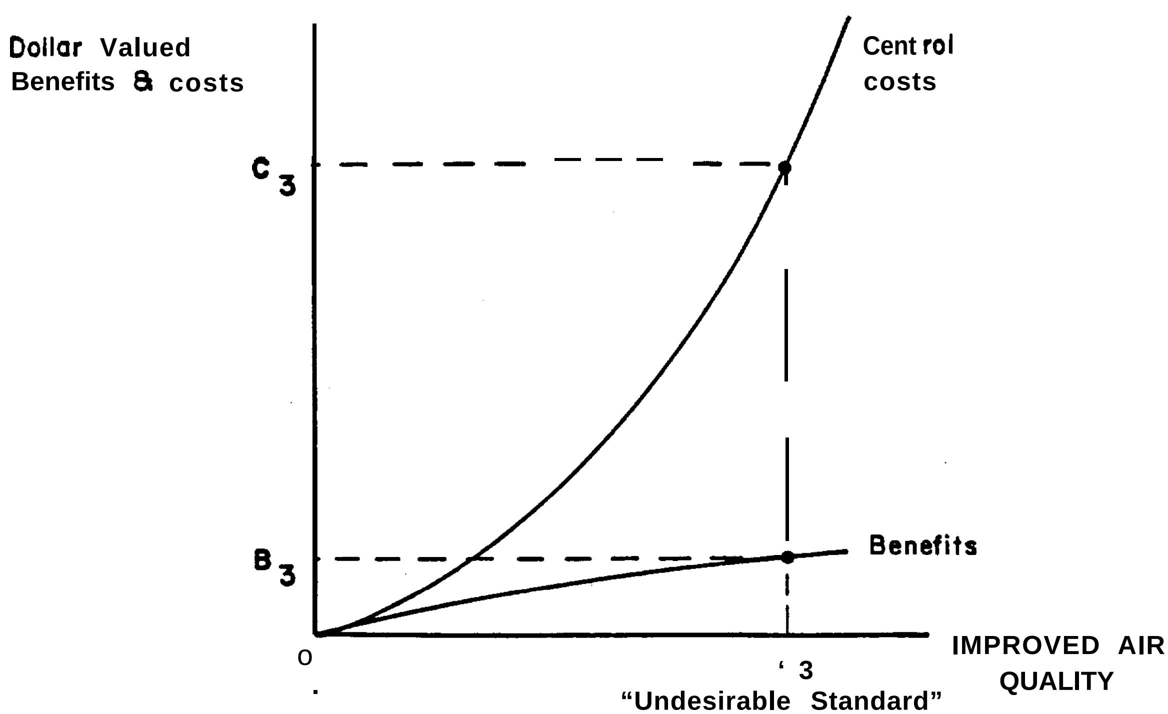



Figure 5.2
The Case of an Undesirable Standard

Basin, the first test for economic efficiency is simply to check if benefits exceed costs. Obviously, it would be desirable to construct benefit and cost curves as shown in Figure 1 to pick the best standards for comparison to actual standards. However, the uncertainty over benefits and especially costs makes such an effort of doubtful value. Rather, given the likelihood of broad ranges for benefits and costs as calculated for the ambient air quality standards, we are interested, from the perspective of economic efficiency, in avoiding either a situation like $S_2$ in Figure 1 or $S_3$ in Figure 2. In both these cases, costs far exceed benefits and it is clear that the standards, $S_2$ or $S_3$, are economically inefficient. In the first case ($S_2$ in Figure 1) the standard has been pushed too far -- to the point where costs of control have risen above benefits, implying excessive standards ($B_2 < C_2$). In the second case ($S_3$ in figure 2), control costs are always above benefits and any standard is undesirable. Given that control costs typically rise very sharply as emission controls become stringent, it is worthwhile, even with uncertain estimates, to check if benefits are at least of the same order of magnitude as costs.

Thus, placed in this perspective our objective is not to develop precise and defensible cost estimates for comparison to benefit measures developed in the preceding chapter, but rather to see if claimed ranges for control cost options to achieve ambient standards possibly allow ambient standards to be met at costs less than benefits.

## BENEFITS FROM AIR QUALITY IMPROVEMENT

### Description of the Study Region[3]

The study area -- the South Coast Air Basin (SCAB) -- consists of Orange and Los Angeles Counties and portions of San Bernadino and Riverside Counties of California. This area has a long history of air quality problems. For instance, Spanish explorers in the sixteenth century noted smoke from Indian campfires in the basin, trapped by inadequate horizontal and vertical air mixing. The post World War 11 period, characterized by Southern California’s rapid population growth and industrial development, was marked by the emergence of photochemical smog as a threat to the regional environment. In response, air pollution abatement programs for stationary sources began in the late 1940’s. Control of mobile source emissions commenced in the early 1960’s, a response to the discovery of the automobile’s role in the smog formation mechanism. Thus, air quality deterioration in the SCAB has multiple causes: topography, meteorology, and dense population and economic activity with correspondingly large emissions.

The SCAB is essentially a coastal plain with connecting valleys and low lying hills bounded by the Pacific Ocean to the south and west and mountain ranges along the inland perimeter [Southern California Association of Governments, et al., (1979)]. Elevation varies from slightly above sea level in the coastal areas to greater than 11,000 feet in the mountainous inland. Intrabasin transport of air pollutants generally follows inland valley pathways.

The main meteorological characteristics of the South Coast Air Basin are mild temperatures, limited precipitation, low wind speeds and persistent inversion layers with low mixing heights. Annual average temperatures range from the low to mid 60's throughout the basin. Variation in temperature is much greater in the eastern portion of the basin due to the decreased oceanic influence. Rainfall amounts vary little throughout the basin and are generally small, typical of a coastal desert. Sunshine is a critical element in the formation of photochemical oxidants, and possible sunshine is generally high. For instance, 73 percent of possible sunshine is recorded annually in downtown Los Angeles.

Low wind speeds with little seasonal variation are a common occurrence throughout the basin. An average wind speed of 5.7 miles per hour has been recorded in downtown Los Angeles over the period 1950 to 1976. The dominant diurnal wind pattern, broken only by the Santa Ana winds and winter storms, is a daytime sea breeze and a nighttime land breeze. Horizontal air movement is, therefore, limited. Vertical dispersion of air pollutants is also limited due to frequent existence of temperature inversions near the surface.

The topographic and meteorological conditions inherent in the South Coast Air Basin imply that the region is limited in its ability to disperse pollutants, both horizontally or vertically. Therefore, pollution emissions have a relatively large impact upon ambient air quality. The situation is further exacerbated since the emission of air pollutants is considerable due to the region's dense population and prosperous economy.

Table 1 presents the air pollution emissions for 1975-76 by major source category for an average summer weekday in the SCAB. Also included are the relative percentage contributions by mobile and stationary sources. These figures represent the baseline emissions for the benefit-cost analysis which follows; that is, the reductions required to attain the federal primary air standards are determined from these baseline statistics. As is illustrated, on-road mobile sources (light duty autos and trucks, medium and heavy duty trucks, heavy duty diesel trucks, and motorcycles) contribute in excess of 50% of total emissions for all pollutants except sulfur oxides and particulate. In these latter categories, stationary sources are the dominant contributors. Offroad mobile sources (aircraft, railroads, ships, etc.) contribute negligible amounts in all cases.

## Table 5.1

**BASE YEAA EMISSIONS 1975 & 1976**

**BY MAJOR SOURCE CATEGORY (TONS/DAY)**

**AVERAGE SUMMER WEEKDAY**

**SCAB**

| SOURCE | THC | | | C | | | CO | | I | | $SO_x$ | | PART | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TONS/DAY | % of Man-Made | % of Total | ONS/DAY | % of Man-mad | % of TOTAL | T ON s/ • | % of TOTAL | TONS/DAY | % of TOTAL | TONS/DAY | % of TOTAL | TONS/DAY | % of TOTAL |
| STATIONARY (Area & Point) | 676 | 38.9 | 23.5 | 510 | 34.5 | 30. I | 215 | 2.6 | 464 | 36.2 | 313 | 81.9 | I 50 | 56.2 |
| On Road Mobile | % 9 | 55.8 | 33.9 | 884 | 59.8 | 52.2 | 7699 | 91.2 | 694 | 54.1 | 37 | 9.7 | 94 | 35.2 |
| Off-bad Mobi 18 | 92 | 5.3 | 3.2 | 84 | 5.7 | 5.0 | 527 | 6.2 | 125 | 9.1 | 32 | 8.4 | 23 | 8.6 |
| Subtotal (Man-Made) | 1737 | 100.0 | | 1478 | 100.0 | | 644 I | 100.0 | 1 283 | 100.0 | 382 | 100.0 | 267 | 100.0 |
| Natural Sources* | 1132 | | 39.5 | 215 | | | | | | | | | | |
| TOTAL | 2869 | | 100.0 | 1693 | | 00.0 | 8441 | 100.0 | 1283 | 100.0 | 382 | 100.0 | 267 | 100.0 |

* Inc.lude> vegetative, landfills and animal waste.

Referent.; AQMP

In Table 2 the emissions inventory is disaggregate by county. As is indicated in the Table, Los Angeles and Orange Counties have a disproportionate share of total emissions, but this corresponds to their shares in population and economic activity.

The existing emissions inventory is such that on virtually every day, at least one of the federal air quality standards is violated at some location in the South Coast Air Basin. For example, the federal oxidant standard (.08 ppm) was exceeded on 252 days in 1976. In addition, the State oxidant first stage episode level of .20 ppm was violated on 204 days in 1976, with a maximum reading of .38 ppm. The nitrogen dioxide standard (.05 ppm) was also consistently violated, with the greatest number of violations occurring in the densely populated areas of Los Angeles and Orange Counties [Southern California Association of Governments, et al., (1979)]. Therefore, significant reductions in existing emissions levels of all pollutants, with the exception of sulfur oxides are required if the South Coast Air Basin is to become an attainment region.

It should be noted that reactive hydrocarbons, nitrogen oxides and carbon monoxide are the pollutants of most importance in the South Coast Air Basin. Significant reductions of total suspended particulate (TSP) are also required to meet the corresponding ambient standards. However, total suspended particulate pollution is primarily background [Southern California Association of Governments et al., (1979]). For this reason, the benefit-cost analysis which follows concentrates on the required reduction of reactive hydrocarbons, nitrogen oxides, and carbon monoxide.

In order to determine the emissions reductions to satisfy the federal standards, one must have knowledge of the relationship between emissions and air quality. However, this is an area characterized by substantial uncertainty and controversy.[4] The estimates used in this analysis are from the Air Quality Management Plan.

This modelling indicated that reactive hydrocarbon emission of 506 tons/day, nitrogen oxides emissions of 800 tons/day and carbon monoxide emissions of 2480 tons/day would allow the federal ambient standards to be satisfied. Therefore, the baseline emissions of reactive hydrocarbons, nitrogen oxides and carbon monoxide would have to be decreased by 974 tons/day, 503 tons/day and 5963 tons/day, respectively [Southern California Association of Governments, et al., (1979)].

Since, the primary concern of this exercise is the evaluation of on-road mobile source controls then the proportion of the required reductions in emissions attributable to these controls was necessary information. This was

Table 5.2

197s-76 Emissions-Major Sources by County
SCAB Average Sumner Weekday

| | Los Angeles County | Orange County | Riverside County | San Bernardino County |
|---|---|---|---|---|
| **Total Hydrocarbons"** | | | | |
| Stationary Manmade | 520.3 | 91.7 | 21.5 | 33.0 |
| Natural | 699.3 | 250.2 | 89.8 | 101.1 |
| On-Road Mobile | 686.9 | 187.1 | 38.4 | 54.6 |
| Off-Road Vehicles | 65.1 | 17.7 | 3.6 | 5.2 " |
| TOTAL | 1971.6 | 546.7 | 153.3 | 193.9 |
| **Reactive Hydrocarbons** | | | | |
| Stationary-Manmade | 393.1 | 69.3 | 16.2 | 24.9 |
| Natural | 91.2 | 24.6 | 60.7 | 43.3 |
| On-Road Mobile | 626.7 | 170.8 | 35.1 | 49.8 |
| Off-Road Vehicles | 59.6 | 16.2 | 3.3 | 4.7 |
| TOTAL | 1170.6 | 280.9 | 115.3 | 122.7 |
| **Carbon Monoxide** | | | | |
| Stationary | 18.9 | 9.1 | 23.2 | 164.2 |
| On-Road Mobile | 5462.2 | 1451.5 | 352.1 | 439.0 |
| Off-Road Vehicles | 373.1 | 99.5 | 24.2 | 30.2 |
| TOTAL | 5854.2 | 1560.1 | 399.5 | 633.4 |
| **Nitrogen Oxides** | | | | |
| Stationary | 347.8 | 32.7 | 6.7 | 50.0 |
| On-Road Mobile | 482.2 | 135.5 | 33.0 | 42.9 |
| Off-Road Vehicles | 86.4 | 24.3 | 5.9 | 7.7 |
| TOTAL | 943.4 | 192.5 | 45.6 | 100.6 |
| **Sulfur Oxides** | | | | |
| Stationary | 234.2 | 22.8 | --- | 55.6 |
| On-Road Mobile | 26.0 | 7.1 | 1.7 | 2.3 |
| Off-Road Vehicles | 22.8 | 6.2 | 1.5 | 2.0 |
| TOTAL | 283.0 | 36.1 | 3.2 | 59.9 |
| **Total Suspended Particulate** | | | | |
| Stationary | 75.5 | 20.7 | 27.0 | 27.2 |
| On-Road Mobile | 65.5 | 18.3 | 4.3 | 5.8 |
| Off-Road Vehicles | 16.2 | 4.5 | 1.1 | 1.4 |
| TOTAL | 157.2 | 43.5 | 32.4 | 34.4 |

Reference: AQMP

calculated as follows. First, baseline emissions (1975-1976) were inflated to reflect the expected growth from the present to 1987, the expected attainment date. This yielded the emissions levels in the absence of control. The inflated emissions were divided into the on-road mobile, off-road mobile and stationary categories assuming that growth in each was proportional to its existing share of the emissions inventory.

Second, from these 1987 emissions levels we subtracted the projected 1987 emissions levels which assume currently mandated controls.[5] The result was the impact of the control measures in each category. Therefore, on-road mobile source controls account for .747, .789 and 1.01 of the reduction in emissions of HC, $NO_x$, and CO from the present to 1987.[6] Finally, these factors were applied to the required emissions reductions stated above. Thus in the scenario analyzed here on-road mobile source controls are responsible for reducing emissions approximately 728 tons/day, 397 tons/day and 6023 tons/day of reactive hydrocarbons, nitrogen oxides and carbon monoxide, respectively. Off- road mobile, stationary and controls make up the balance of the control effort designed to attain the Federal Ambient Standards.

## The Benefits of Emissions Reductions

The benefits from air quality improvements are derivable from either the housing value method or the survey approach detailed in the previous chapter. However, the housing value approach, which allows the derivation of an estimated relationship between pollution abatement benefits and the independent variables income and initial pollution concentration, is more amenable to this policy application. For this reason, the housing value approach is the primary method employed to estimate benefits from the air quality improvement associated with the stated emissions reductions.

The housing value analysis used is a multi-step procedure:[7] (i) estimation of a hedonic housing value equation which relates home sale price to a set of home and neighborhood variables; (ii) derivation of marginal willingness to pay for air quality improvement; (iii) estimation of a marginal benefit equation which relates marginal willingness to pay to income and existing pollution levels (i.e., this is the inverse demand curve); and (iv) mathematical integration of the marginal benefit equation to determine total household benefits for any stated air quality improvement. This final step is equivalent to determining the area under the inverse demand relationship. It is this latter relationship that is used to determine basinwide benefits for any decrease in pollutant concentrations by applying the household benefits to the relevant population.

The multi-step nature of the housing value approach produces a resulting benefit equation which is inherently dependent upon previous steps. For instance, collinearity among the various pollution measures dictated the use of nitrogen dioxide ($NO_2$) as a proxy for overall pollution. Also, there existed no significant difference in statistical performance in the hedonic housing equation between $NO_2$ measured as $NO_2$, $NO_2^2$, or $NO_2^3$. However, the resulting benefit estimates were substantially affected by the choice of measurement. Variation in the third procedural step estimation of the marginal benefit relationship was found not to alter the benefit results measurably; that is, benefit estimates were essentially invariant to the form of the estimated relationship (linear-linear, log-log). Therefore, benefits from air quality improvement are not determined uniquely, rather a range results are obtained depending upon the particular estimation procedure used.

In total, six estimated benefit equations, determined by the pollution variable used in the initial step ($NO_2$, $NO_2^2$, $NO_2^3$) and the form of the marginal benefit equation (linear-linear, log-log), were utilized to calculate household benefits. The general structure of the benefit equations corresponding to the linear-linear marginal benefit equations is

$$HB = C_1 \cdot (P_B - P_A) + C_2 \cdot (P_B - P_A) \cdot Y + C_3 \cdot (P_B^2 - P_A^2)$$

where

$HB$ = household benefits in dollars
$P_B$ = initial pollution ($NO_2$) level in pphm
$P_A$ = pollution ($NO_2$) level after proposed improvement in pphm
$Y$ = income in dollars

$C_1, C_2, C_3$ = estimated coefficients determined by integration of the appropriate marginal benefit function.

The general benefit equation corresponding to the log-log marginal benefit equations is

$$HB = C_1 \cdot Y^{C_2} \cdot P_B^{C_3} - P_A^{C_3} \cdot C_3$$

Table 3 presents the estimated coefficients.

In order to demonstrate the use of the benefit equations, consider Figure 3. The figure shows a family of constant benefit curves which indicate all combinations of income and existing pollution that yield an identical willingness to pay (dollar amount over the life of the home) to achieve the ambient standard. As is evident, those individuals with high income and poor air quality would be willing to pay the most for the stated air quality

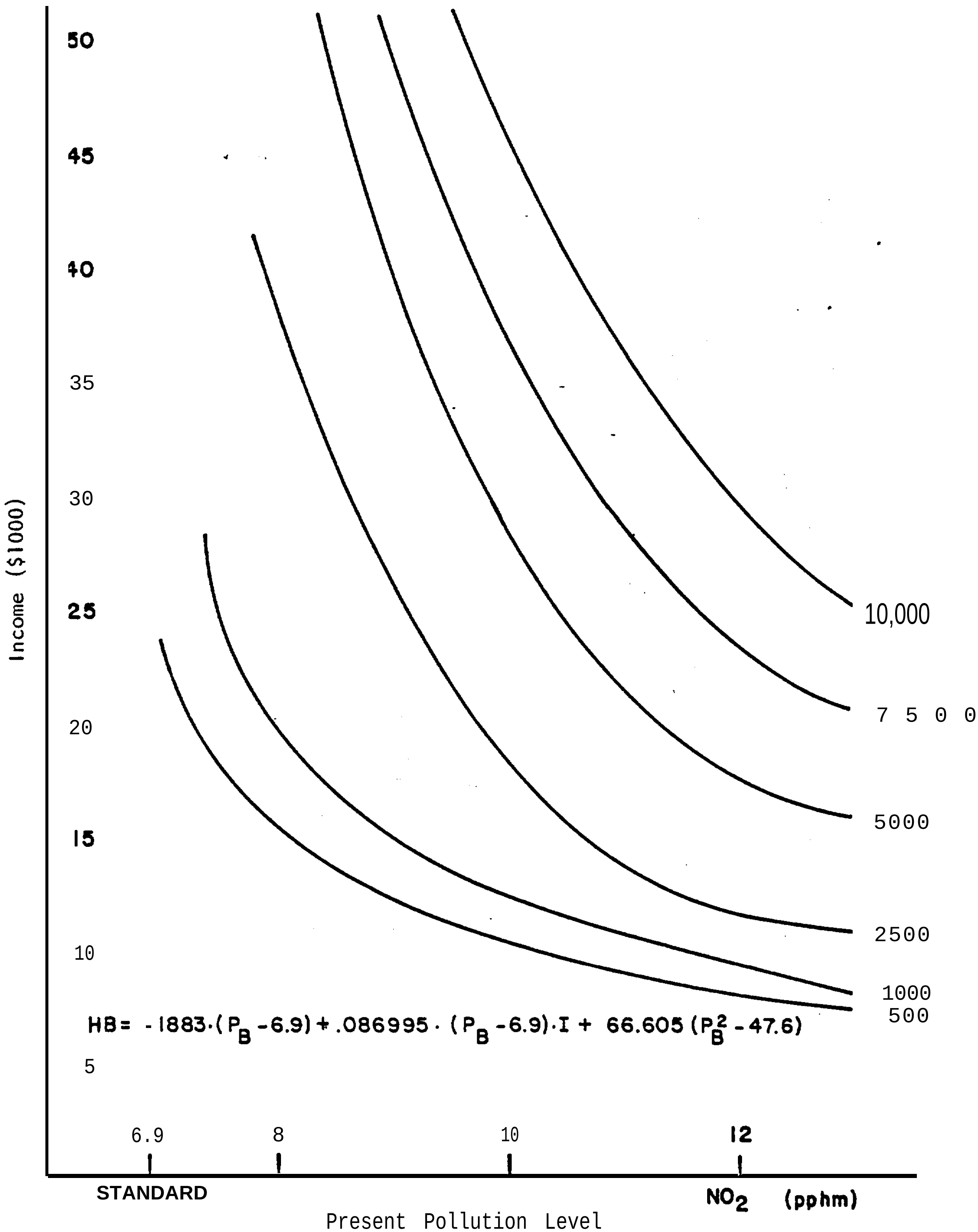
TABLE 5.3

**Benefit Equation Coefficients**

| | Pollution Variable Used in Hedonic Housing Value Equation | | |
|---|---|---|---|
| **Linear - Linear Marginal Benefit Function** | $NO_2$ | $NO_2^2$ | $NO_2^3$ |
| $C_1$ | 53.996 | -1883.1 | -2294.5 |
| $C_2$ | .11513 | .086995 | .057521 |
| $C_3$ | -31.204 | 66.605 | 95.145 |
| **Log - Log Marginal Benefit Function** | | | |
| $C_1$ | .024134 | .001785 | .000115 |
| $C_2$ | 1.1983 | 1.1985 | 1.1988 |
| $C_3$ | .69054 | 1.69195 | 2.691 |

Figure 5.3

**VALUE OF IMPROVED AIR QUALITY ($)**



improvement. Further, an individual with relatively high income and good air quality would be willing to pay as much as an individual characterized by poor air quality and low income.

Benefits derivable from moving to the ambient standard can be calculated given values for income and baseline pollution in all areas. In the context of the earlier discussion, this constitutes improving the "fair" and "poor" air quality areas to the "good" category. The fair and poor regions are assigned values of 9.55 pphm and 12.38 pphm, respectively, as determined by the sampling procedure outlined in Chapter 3. Therefore, if all regions were to upgrade to the "good" level, it would involve an approximate 30% improvement in the fair communities and a 45% improvement in the poor air quality communities.

With respect to income data, two methods were initially utilized. In the first method each household was allocated the county average income. The second procedure assumed that the good air quality region was inhabited by an income group wealthier than average. Thus, on the basis of the survey responses the good air quality area income was determined and then separated out from total county income. Each household in the poor and fair air quality regions was then allocated the average of the remaining income. This second method, although somewhat lowering average income per household in the poor and fair communities had little effect on aggregate benefit estimation. Thus, results are presented for the first method only.

With all data inputs specified, household benefits are calculated using the estimated benefit equations. These benefits which accrue over the life of the home, represent differences in home sale price attributable to variations in air quality. In order to transform these into annual benefits the standard annualization procedure is employed (1978 interest rate = .10). Aggregation is then accomplished for each county by deflating by persons per household and multiplying by county population. This generalization to the entire county assumes that the household sample analyzed is representative of the population at large.

Aggregate benefits associated with achieving the federal air quality standards in the South Coast Air Basin are presented in Table 4. As is illustrated, aggregate benefits range from 1.5 to 3.8 billion dollars annually. Further, the bulk of the benefits occur in populous Los Angeles and Orange counties. The upper bound estimate corresponds to the benefit equations derived from the use of $NO_2$ in the hedonic housing equation (initial step of the multi-step procedure) whereas the lower bound corresponds to the use of $NO_2$. The form of the estimated marginal benefit function has no significant impact on the benefit estimates.

Table 5.4

**Annualized Benefit Estimates for Achieving the Federal Ambient Standard (1978 $000)**

| Functional Form | | County | | | | |
|---|---|---|---|---|---|---|
| **Pollution Variable** in Hedonic Housing Equation | **Functional Form** of Marginal Benefit Function | **San Bernardino** | **Riverside** | **Orange** | Los Angeles | Total |
| $NO_2$ | Linear - Linear | 295708 | 234345 | 638571 | 2711045 | 3879669 |
| $NO_2^2$ | Linear - Linear | 194455 | 153284 | 414687 | 1776702 | 2539128 |
| $NO_2^3$ | Linear - Linear | 118541 | 93117 | 245573 | 1065688 | 1522919 |
| $NO_2$ | Log - Log | 287443 | 228393 | 615769 | 2611015 | 3742620 |
| $NO_2^2$ | Log - Log | 204302 | 162331 | 413405 | 1789905 | 2569943 |
| $NO_2^3$ | Log - Log | 129231 | 102681 | 246916 | 1092596 | 1571424 |

For purposes of comparison, the survey approach which accompanied the property value analysis, yields an aggregate benefit estimate of approximately 1.65 billion dollars annually, whereas a housing value analysis which utilized total suspended particulate as the proxy variable yields estimates in the 2.2 to 2.7 billion dollar range. Based on this evidence, a narrowing of the probable range of benefits to 1.6 to 3.0 billion dollars annually seems in order.

Apportionment of these benefit figures between the on-road mobile, off-road mobile and stationary categories is accomplished through application of the percentage figures described above. Using the percentage averages over reactive hydrocarbons, nitrogen oxides and carbon monoxide then on-road mobile controls are assigned approximately 85% of the benefits. Therefore, the benefits from air quality improvement associated with on-road mobile controls range from 1.36 - 2.55 billion dollars annually. Again, the remainder of air quality improvement benefits are a function of off-road and stationary and institutional control measures.

Before proceeding to the next section two qualifications should be noted. First, the benefit calculations are inherently tied to both the air pollution modeling efforts contained in the Air Quality Management Plan and the estimation procedures outlined in Chapter 3. Second, it should be noted that these benefit calculations were derived assuming a one year cleanup period. This essentially static analysis is somewhat unrealistic given the magnitude of the air quality problem in the SCAB.[8] A dynamic approach which examined the benefits resulting from a multi-year clean-up would indicate expanded benefits due to increased population and economic growth and associated increased emissions levels. The increased emissions would imply a larger required emission reduction to satisfy the federal standards and a corresponding larger benefit per household. The greater population would increase aggregate basin-wide benefits.

In the next section, dollar per ton removed cost estimates are presented for on-road mobile pollution control methods. These cost estimates are then used to determine total clean-up costs for the required emissions reductions.

## ESTIMATED COSTS OF AIR QUALITY IMPROVEMENT

### Institutional Background

Control of vehicular emissions began in 1961, when the automakers, under pressure from the California legislature, installed positive crankcase ventilation (PCV) systems in order to reroute "blowby" fumes back into the engine intake.[9] These emissions had been discovered two years earlier to account for 20-25 percent of hydrocarbon emissions. Positive crankcase ventilation was adapted nationwide in 1963 [Mills, et al. (1978), and Wakefield, (1980)].

The 1965 amendments to the Clean Air Act directed the secretary of HEW to set emissions standards for automobiles effective January 1, 1968. The Clean Air Act was further amended in 1970 setting goals of 90 percent reductions in emissions from automobiles by 1975-76. The objective of such legislation seemed reasonable; fewer pollutants, more efficient engines. However, the attainment of such objectives has been a difficult process.

Emission standards were first set for hydrocarbons (HC) and carbon monoxide (CO); the 1970 standards were 2.2 grams/mile and 23 grams/mile respectively (7-mode test). In the early years the control of those pollutants focused on modification of existing engines. The original modifications (leaner air-fuel mixtures, retarded ignition timing and higher coolant temperatures) were relatively unsuccessful, causing associated side effects (reduced fuel economy and engine response). Later modifications proved more successful both in combatting pollution and reducing the unwanted side effects.

California was the first to set a limit on nitrogen oxide ($NO_x$) emissions -- 4.0 grams/mile for the 1971 year. This was in response to $NO_x$ being identified as an important element in the formation of photochemical smog. However, the control of $NO_x$ introduced an inherent conflict. Hydrocarbon and carbon monoxide control had been achieved by afterburning through air injection, delaying spark, leaner mixtures or hotter combustion. Nitrogen oxide control required reducing temperature since they were a byproduct of very hot, relatively efficient combustion. This was accomplished by exhaust gas recirculation (EGR) which had dramatic negative impacts on fuel mileage and driveability (response to acceleration and performance under constant speed [Wakefield, (1980)].

Even though the original 1975-76 standards were delayed considerably the 1975 federal emission regulations were so stringent (1.5/15/3.1 grams per mile of HC/CO/$NO_x$ using the Constant Volume Sampling - 75 test) as to require a technological revolution. The catalytic converter was introduced. Since the catalytic converter was downstream from the engine operation it freed the engine from earlier modifications. This meant better engine response and fuel economy from a given engine controlled with a catalyst rather than controlled without a catalyst.

The first catalytic converters controlled HC and CO leaving $NO_x$ to be controlled by conventional means. However, 3-way catalytic converters in which two separate catalyst beds control HC, CO and $NO_x$ now exist. This latter innovation, together with advances in electronic monitoring have allowed control of vehicular emissions while minimizing the effects on driveability and fuel economy. However, this is sophisticated and costly technology. It is the costs we turn to next.

## The Costs of Emissions Reductions

The estimation of control costs is characterized by controversy and a large degree of uncertainty. The difficulty in estimation is concentrated around two central problems. The first is determining the actual cost of any particular control technique. In many instances, with very little construction experience, the cost of specific control devises is unknown. Also, marketing strategies affect the direct cost to the consumer. For example, the cost of California systems which requires larger emission reductions than their federal counterparts may be spread out among all automobile consumers rather than those located in California. Further, control techniques generally imply associated secondary costs and savings which often escape quantification. These secondary implications can have a significant impact on the cost of any proposed control option.

The second problem is the determination of actual, rather than alleged, emissions reductions corresponding to any particular control strategy. For instance, control strategies may cause synergistic reductions or may negate each other. In addition, control strategies may be credited with either overstated or understated emission reductions. The former problem, phantom decreases in emissions, seems to occur more often in practice.

Therefore, any cost analysis which is not fortified by detailed engineering cost evaluation and experience is subject to significant error. This problem is further exacerbated in that estimation errors are generally not randomly distributed.[10]

Given the background of controversy and substantial uncertainty, the objective here is to provide a range of cost estimates to be used for comparison to the benefit calculations presented in the previous section. The cost estimates contained herein were derived from a variety of sources, primarily from Environmental Protection Agency (EPA) publications and automobile manufacturer statements. All costs are stated in 1978 dollars per ton removed.

Due to the automobile's substantial role in the South Coast Air Basin air quality problem (see Tables 1 and 2) mobile source control must be the central element in any attainment plan. However, control cost figures associated with any level of control vary widely, dependent upon one's assumptions regarding initial capital cost, size of any mile per gallon benefit or penalty, unleaded fuel cost differential, etc. In order to offset some of the variation we standardized the cost estimates by assuming the following: (1) control cost devices have a lifetime of 50,000 miles; (2) the cost of gasoline is $1.00/gallon; (3) the unleaded fuel cost differential is $.04/gallon [Lloyd, (1979)]; (4) baseline mileage is 20 miles per gallon [11]; (5) maintenance savings are $25 over the life of the emissions system [Lloyd, (1979)]; (6) evaporative emissions and altitude control add $15 to initial capital costs; and (7) the capital costs of going from totally uncontrolled vehicles to the 1977-79 standard of 1.5/15/2.0 of $HC/CO/NO_x$ is $140 [Lloyd, (1979)], where uncontrolled vehicles correspond to the 1973 federal standard (Constant Volume Sampling-72 test) of 3.4/39/3.0.[12] Further, we examined the total cost of moving from this 1973 level of control to the 1981 federal standard of .41/3.4/1.0.

Even with this degree of standardization there exists significant variation in mobile control costs dependent upon the source of information, the assumed fuel mileage savings or penalty and the assumed allocation of total costs to hydrocarbon, carbon monoxide and nitrogen oxide control. Tables 5, 6, and 7 present this range of cost estimates for light duty vehicles.

Each of the tables uses the same references to generate total control costs. The General Motors estimate is based upon initial capital costs of $460 and a three percent mileage penalty, whereas the EPA estimate is $415 for initial capital cost with a seven percent mileage improvement. The American Motors and manufacturer average sticker price estimates for first cost are $557 and $475 respectively. These are combined with the General Motors and EPA mileage penalty or saving estimates to obtain two of the estimates presented. The third estimate assumes an eight percent mileage penalty [California Air Resources Board, (1979)]. Cost effectiveness is then determined by dividing the total cost per car by the emission reduction over 50,000 miles.

In Table 5 the lower bound figure of the range for each cost-effectiveness estimate is based upon an allocation of 30.4 percent of the total control cost to hydrocarbon measures [Schwing, et al., (1980)]. The upper bound figures assume one-third of total cost is allocated to hydrocarbon control. In Table 7, the upper bound figures for each estimate correspond to an allocation of .33 and .362 to nitrogen oxides control [Schwing, et al., (1980)]. The figures in Table 6 assume one-third of total cost is allocated to carbon monoxide control.

As is illustrated in the tables, the cost effectiveness range ($/ton

Table 5.5

**Hydrocarbon Cost Estimates for Mobile Source Control**

**($1978/ton removed)**

| Control Category | cost | Reference |
|---|---|---|
| Light Duty Vehicles | $ 160- 257 | General Motors (GM)[1] |
| | 620- 680 | EPA[2] |
| | 880- 965 | American Motors[3], EPA Mileage |
| | 1340- 470 | American Motors, GM Mileage |
| | 1610- 770 | American Motors, Eight Percent Mileage Penalty |
| | 730- 800 | Manufacturer Average[4], EPA Mileage |
| | 1190-1310 | Manufacturer Average, GM Mileage |
| | 1460-1600 | Manufacturer Average, Eight Percent Mileage Penalty |
| Heavy Duty Vehicles | 3400-3450 | AQMP[5] |
| | 3720-3770 | EPA |
| Inspection and Maintenance | 1410-1590 | AQMP |

References: 1. General Motors Corporation, "Estimated Effects of Exhaust Emission Standards on Potential Hardware, Fuel Economy, Fuel Consumption and Additional First Cost to Consumer," May 1979.

2. Lloyd, Kenneth H., Cost and Economic Input Assessment for Alternative Levels of the National Ambient Air Quality Standard for Ozone, USEPA, February 1979.

3. American Motors Corporation Cost Information contained in "Automobile Emission Control - The Development, Status, Trends and Outlook as of December 1976," USEPA, April, 1977.

4. California Air Resources Board, "Status Report on the Need for Land Feasibility of a 0.4 $NO_x$ standard for Light Duty Motor Vehicles, December 1979.

5. Southern California Association of Governments and South Coast Air Quality Management District, Draft Air Quality Management Plan, January, 1979.

Table 5.6

**Carbon Monoxide Cost Estimates for Mobile Source Control**

($1978/ton removed)

| Control Category | cost | Reference |
|---|---|---|
| Light Duty Vehicles | 160 | General Motors (GM)[1] |
| | 85 | EPA[2] |
| | 120 | American Motors[3], EPA Mileage |
| | 184 | American Motors, GM Mileage |
| | 220 | American Motors, Eight Percent Mileage Penalty |
| | 100 | Manufacturer Average[4], EPA Mileage |
| | 163 | Manufacturer Average, GM Mileage |
| | 200 | Manufacturer Average, Eight Percent Mileage Penalty |
| Heavy Duty Vehicles | 290-310 | AQMP[5] |
| | 320-340 | EPA |
| Inspection and Maintenance | 175-195 | AQMP (Revised) |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1. General Motors Corporation, "Estimated Effects of Exhaust Emission Standards on Potential Hardware, Fuel Economy, Fuel Consumption and Additional First Cost to Consumer," May 1979.

2. Lloyd, Kenneth H., Cost and Economic Input Assessment for Alternative Levels of the National Ambient Air Quality Standard for Ozone, USEPA, February 1979.

3. American Motors Corporation Cost Information contained in "Automobile Emission Control - The Development, Status, Trends and Outlook as of December 1976," USEPA, April, 1977.

4. California Air Resources Board, "Status Report on the Need for Land Feasibility of a 0.4 $NO_x$ standard for Light Duty Motor Vehicles, December 1979.

5. Southern California Association of Governments and South Coast Air Quality Management District, <u>Draft Air Quality Management Plan</u>, January, 1979.

Table 5.7

**Oxides of Nitrogen Cost Estimates for Mobile Source Control**

**($1978/ton removed)**

. . .

| Control Category | cost | Reference |
|---|---|---|
| Light Duty Vehicles | 1910-2070 | General Motors (GM)[1] |
| | 1010-1100 | EPA[2] |
| | 1440-1570 | American Motors[3], EPA Mileage |
| | 2200-2390 | American Motors, GM Mileage |
| | 2640-2870 | American Motors, Eight Percent Mileage Pena 1 ty |
| | 1195-1300 | Manufacturer Average[4], EPA Mileage |
| | 1950-2120 | Manufacturer Average, GM |
| | 2390-2600 | Manufacturer Average, Eight Percent Mileage Penalty |
| Heavy Duty Vehicles | 2020-2120 | AQMP[5] |
| | 2210-2320 | EPA |
| Inspection and Maintenance | 1310-1600 | AQMP |

References: 1. General Motors Corporation, "Estimated Effects of Exhaust Emission Standards on Potential Hardware, Fuel Economy, Fuel Consumption and Additional First Cost to Consumer," May 1979.

2. Lloyd, Kenneth H., Cost and Economic Input Assessment for Alternative Levels of the National Ambient Air Quality Standard for Ozone, USEPA, February 1979.

3. American Motors Corporation Cost Information contained in "Automobile Emission Control - The Development, Status, Trends and Outlook as of December 1976," USEPA, April, 1977.

4. California Air Resources Board, "Status Report on the Need for Land Feasibility of a 0.4 $NO_x$ standard for Light Duty Motor Vehicles, December 1979.

5. Southern California Association of Governments and South Coast Air Quality Management District, Draft Air Quality Management Plan, January, 1979.

removed) for hydrocarbon control is approximately $600 - $1800 while carbon monoxide control is $80-$200 and $NO_x$ control is $1000-$2600. The predominant source of this wide variation is the assumption concerning fuel use over the 50,000 mile life of the control device.

The cost effectiveness of heavy duty vehicle emissions control were calculated in a manner similar to that described above for light duty vehicles. In this instance total cost per vehicle figures published in the Air Quality Management Plan (January, 1979) and an EPA report [Lloyd, (1979)], were utilized. The former reference was also the source for the corresponding emissions reductions. Total vehicle cost includes all capital costs and costs for the associated inspection and maintenance program. Cost effectiveness estimates for heavy duty vehicles are presented in Tables 5, 6, and 7 for the pollutants HC, CO, $NO_x$, respectively. Again, the range of costs is dependent upon the allocation method used; either one-third to each pollutant or .329 to HC, .354 to CO and .317 to $NO_x$, [Schwing, et al., (1980)].

The final component of on-road mobile source control is the light duty vehicle inspection and maintenance program. The importance of this program cannot be understated for without it, auto owners have no incentive to maintain the performance of their emission control systems. Furthermore, the lack of performance invalidates the cost-effectiveness figures presented above which assume that the control devices work as designed. For example, if control mechanisms on light duty vehicles deteriorate linearly over 50,000 miles from their designed operations levels then the cost effectiveness of such mechanisms doubles. This situation is worsened if systems deteriorate more quickly or are tampered with. The success of any control system is therefore inherently dependent on an effective inspection and maintenance program.

The annual cost of the program is the sum of the inspection fee multiplied by number of automobiles plus the cost of repairing failed automobiles. The air quality management plan assumes a $9 inspection fee, and a 35 percent failure rate with associated $23 repair cost. However, recent evidence shows that the failure rate may be closer to 42 percent.[13] The cost calculations contained in Tables 5, 6, and 7 assume this latter figure with a corresponding repair cost range of $20 - $25. Emissions reductions associated with the inspection and maintenance program were obtained from the Air Quality Management Plan (January, 1979). Allocation of total cost among the pollutants was based on either one-third to each pollutant or the proportions used for light duty vehicles [Schwing, et al., (1980)].

Any control strategy devised to meet the ambient standard would use a variety of control options, each with an associated cost effectiveness.

Therefore, the cost effectiveness figures for light duty vehicles, heavy duty vehicles and the inspection and maintenance program form the basis for the derivation of aggregate cost estimates to achieve the federal ambient standards.

It is not the objective of this exercise to cost out a specific air quality improvement program, but rather to develop a range of costs for comparison to benefits. This can be accomplished by an examination of an upper and lower bound for costs. In either case, a weighted average of light and heavy duty vehicle costs and the inspection and maintenance costs is utilized, where light duty vehicle costs are the dominant component.

As was stated in the previous section on-road mobile controls account for approximately 85 percent of the required emissions reductions. This translates into 728 tons/day of HC, 6023 tons/day of CO and 392 tons/day of $NO_x$. In order to estimate total control costs these emissions reductions are further apportioned into the light duty vehicle, heavy duty vehicle and inspection and maintenance categories. Reductions associated with inspection and maintenance are determined directly from the Air Quality Management Plan (January, 1979). The shares corresponding to light duty vehicles and heavy duty vehicles are determined by their relative shares in annual vehicle sales. Therefore, three percent of the required reductions minus the effect of inspection and maintenance are allocated to heavy duty vehicles with the remainder to light duty vehicles.

A lower bound total cost estimate would correspond to the EPA capital cost, a seven percent mileage improvement and one-third allocation to each pollutant. In this case total cleanup costs for on-road mobile controls would be approximately .61 billion dollars. Conversely, an upper bound estimate would be 1.32 billion dollars. This latter estimate would utilize American Motors capital costs, an eight percent mileage penalty and one-third allocation to each pollutant. Thus, the total cost of using on-road mobile controls to achieve the above stated pollution reductions range from approximately .61 to 1.32 billion dollars. A best estimate (manufacturer average capital cost, three percent mileage penalty) would be 1.02 billion dollars.

Before proceeding to the concluding section it should be re-emphasized that these cost figures are subject to a great deal of uncertainty. There could be significant error in the estimates. It should also be noted that, as in the case of the benefit estimate, this is an essentially static analysis. In a dynamic context, one would expect the costs to increase significantly as a result of larger emission reductions necessitated by expanded population and economic activity. The costs would likely increase non-linearly as more costly control measures were employed to achieve the required reductions.

This latter aspect exists because many of the easy technological fixes have already been made.

## COMPARISON OF BENEFITS TO COSTS - CONCLUDING REMARKS

There has been much discussion of the desirability of achieving the federal air quality standards. This study constitutes an attempt to evaluate a portion of these standards in the South Coast Air Basin of Southern California from an economic or benefit-cost perspective. Based upon modeling contained in the Air Quality Management Plan, achievement of the ambient standards in 1979 would require emission reductions of the 974 tons/day, 5963 tons/day and 503 tons/day of reactive hydrocarbons, carbon monoxide and nitrogen oxides. It is the share of these emission reductions attributable to on-road mobile source control which was evaluated using benefit-cost analysis.

Benefits were calculated through an examination of housing value differentials attributed to air quality. Achieving the ambient air quality standards was consistent with improving the "fair" and "poor" air quality regions to the "good" category as specified in the previous chapter. In effect, this constituted an approximate 30 percent improvement in the fair areas and a 45 percent improvement in the poor air quality areas. Corresponding benefits were estimated to fall between 1.6 and 3.0 billion dollars per year, independent of any benefits accruing to agriculture and ecosystems. The share of these benefits associated with on-road "mobile source control was estimated to be 1.36-2.55 billion dollars.

Cost estimates were developed from existing data sources, primarily from manufacturer statements and government publications. Given the variation in control cost options and the uncertain nature of the cost figures, it was found that on-road mobile source control consistent with a policy to achieve the ambient standards in 1979 would involve a cost of between ,61 and 1.32 billion dollars, with a best estimate of 1.02 billion dollars.

It seems then, that the benefits from on-road mobile emissions reductions consistent with satisfying the ambient standards are of the same order of magnitude as the cost estimates. This implies that the ambient air quality standards are not without some economic justification, though the uncertainty concerning the benefit and cost calculations prevents one from accepting the controls outright. However, on-road mobile controls consistent with the air quality standards cannot be rejected as economically inefficient either.

Therefore, although the mid-range benefit estimate exceeds the mid-range cost estimate, the situation is best characterized as highly uncertain. Further, the static analysis performed herein does not answer significant questions concerning the behavior of the benefit and cost functions over time. Stronger statements could only be made in the context of a much more detailed analysis supported by a solid cost data base.

## Appendix 1
## Air Quality Modelling in the
. . .
## Air Quality Management Plan

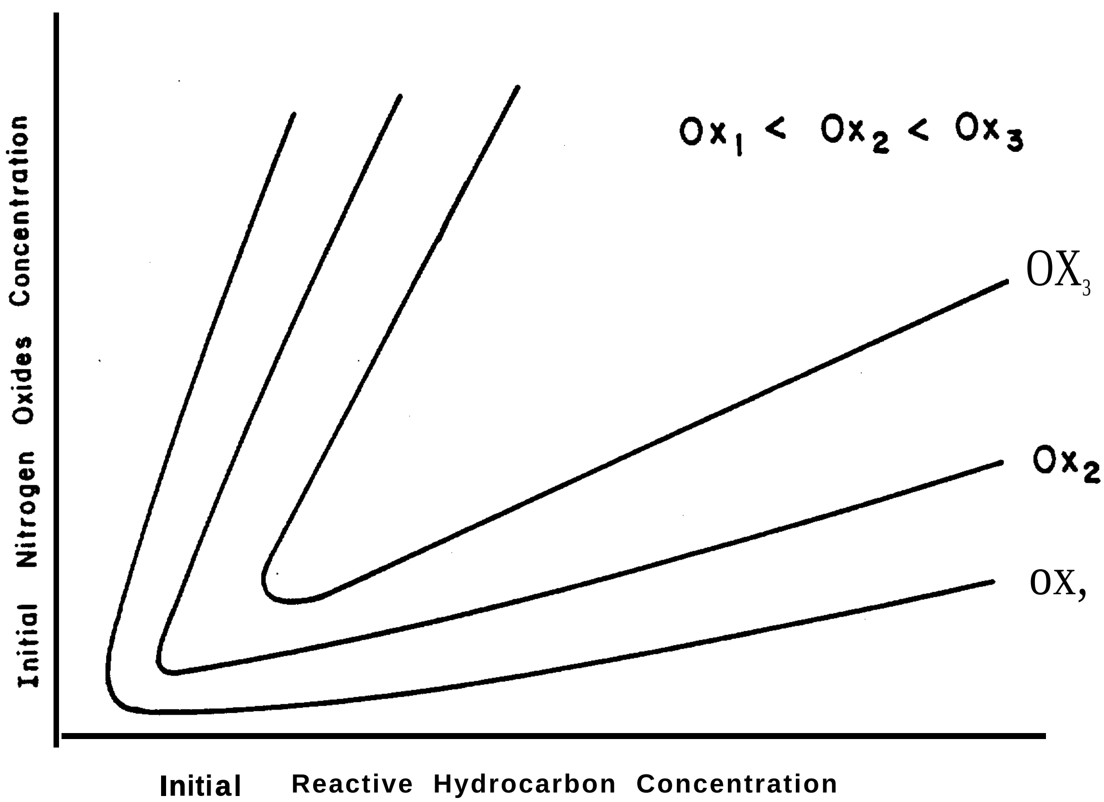
The principal modeling procedure utilized in the Air Quality Management Plan is proportional rollback. This method is based on the assumption that atmospheric concentrations of the contaminant are in direct proportion to emissions. Mathematically, the proportional rollback method can be expressed as:

$$\frac{\text{Baseline Emissions}}{\text{Emissions Objective}} = \frac{\text{Baseline Air Quality}}{\text{Air Quality Objective}} .$$

The emissions level consistent with the federal standards (objective) can then be determined with knowledge of the other three components. The procedure was employed to calculate the required reductions of carbon monoxide. A somewhat more sophisticated rollback method was used for total suspended particulate [Southern California Association of Governments and South Coast Air Quality Management District, (1979)]. The rollback method provides an accurate assessment of emissions reductions required in cases where the contaminant is emitted uniformly over the region and there are only limited atmospheric reactions among pollutants. Accuracy is severely curtailed when these conditions are not satisfied. In the South Coast Air Basin, where pollutants are emitted nonuniformly with nonuniform distribution and photochemical oxidants are the primary problem, the linear rollback method is of limited usefulness. Therefore, ozone production was modeled in the AQMP using the Empirical Kinetic Modeling Approach (EKMA).

The EKMA Method is a mathematical model which generates a set of atmospheric ozone concentration isopleths as a function of early morning concentrations of hydrocarbons and nitrogen oxides [Mikolowsky, et al, (1974) and Southern California Association of Governments and South Coast Air Quality Management District, (1979)]. Figure Al illustrates the inherent nature of the ozone isopleths (curves of equal concentration). The curvature of the isopleths indicates that a control strategy which reduced only one of the pollutants -- reactive hydrocarbons or nitrogen oxides -- could conceivably worsen rather than improve the situation. The proper control strategy would, therefore, require that both pollutants be reduced simultaneously.

Figure 5.A1




OZONE ISOPLETHS

# REFERENCES

1 Note, for example, that the average daily maximum concentration of NO in "good" air quality communities is .069 ppm where the ambient standard[2] required an average concentration of .05 ppm.

2 In addition to the difficulty in obtaining accurate cost data on stationary and institutional controls the decision to focus on on-road mobile source control was a function of its relative share of both existing pollution and the future clean-up as envisioned in the Air Quality Management Plan (January, 1979).

3 The area description follows closely the Air Quality Management Plan (January, 1979).

4 A brief discussion of air quality modelling is contained in the appendix to this section.

5 Air Quality Management Plan (January, 1979).

6 The share of the reduction in CO attributable to on-road mobile sources estimated to be in excess of 1.0 indicated an increase in CO emissions from off-road mobile sources and neither an improvement nor deterioration from stationary sources.

7 See Harrison and Rubinfeld (1978) for a detailed description of the methodology.

8 Although the static approach is somewhat unrealistic it was chosen since there was insufficient data on costs and the dynamics of pollution emissions, population, etc. to support analyzing a particular attainment plan.

9 Blowby is the collection of combustion gases that slip past the piston rings from the combustion chamber into the crankcase. These fumes were vented to the atmosphere to prevent contamination and thinning of

crankcase oil [Mills, et al. (1978) and Wakefield (1980)].

10 Personal Communication with Dr. Richard Perrine, UCLA.

11 The 20 miles per gallon assumption corresponds to the CAFE mileage standards for 1980 on a sales weighed basis. Further, these standards are front loaded up to 27.5 MPG in 1985. Thus, using 20 MPG overstates the lifetime fuel cost differential and the mileage penalty.

12 Even though the 1973 federal standard was chosen as the level of uncontrolled emissions, the 1973 levels represent approximately 61%, 55% and 25% control over truely uncontrolled emissions of HC, CO and NO respectively. The 1973 level was chosen to be conservative (overstate) in the cost effectiveness of emission control devices.

13 Personal communication with Dr. Richard Perrine, UCLA.

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# CHAPTER 6

# EFFECTS OF AIR POLLUTION AND OTHER ENVIRONMENTAL VARIABLES ON OFFERED WAGES

## INTRODUCTION

Much of the recent interest in the econometric estimation of labor supply models using individual or micro data has been stimulated by important policy questions such as the role of women in the labor force and the advisability of negative income tax programs. Frequently, these models have consisted of two interrelated equations that explain: (1) how an individual's offered wage rate is determined and (2) how this wage rate together with other factors affects the amount of time an individual chooses to work. Effects on wages and hours in response to changes in exogenous variables including the actual negative income tax rate faced or the number of pre-school children in the home can then be estimated through this framework. This general approach can be easily extended to make parallel estimates of the labor market effects of changes in environmental amenity levels. Such extensions would have obvious policy relevance in that the extent of reduced productivity due, for example, to air pollution could then be assessed.

The purpose of this report is to construct some exploratory estimates of the effect of changes in air pollution levels on offered wage rates. Repercussions on the work time choice are not explicitly considered. Specifically, hedonic equations are estimated that allow for an individual's offered wage rate to be determined by his own labor supply characteristics together with measures of amenity levels in the community in which he lives. In this type of analysis, supply characteristic's such as education, work experience, and health status are frequently used exclusively to explain the variation in the offered wage.[1] This specification carries the restrictive implicit assumption that the demand schedule for classes of individuals possessing identical values of these independent variables is infinitely elastic. That is, observed differences in individual wage rates are attributed only to supply characteristics. In order to circumvent this limitation, Nakamura, Nakamura, and Cullen (NNK) (1979), have suggested the inclusion of work environment variables such as the local unemployment rate and a local job opportunities index as additional regressors. These work environment variables, obviously) capture the fact that local labor demand conditions may influence offered wages after adjusting for the effect of individual labor supply characteristics. However, as recognized by other investigators, variables measuring working conditions and job related hazards (Lucas 1977, Hamermesh 1977, Thaler and Rosen 1975, Viscusi 1978, and Brown 1980), social infrastructure (Nordhaus and Tobin 1972, and Meyer and Leone 1977), as well as environmental amenities (Hoch 1977, Rosen 1979, and Cropper 1979) can also play an important role, in explaining the behavior of wage rates. For example, in the case of environmental amenities, 'if a community is located in an area that is subject to extreme temperatures or unusually high air pollution levels, employers may find it necessary to pay their workers a premium in order to induce them to remain there.

SPECIFICATION AND THE DATA USED IN ESTIMATION

The general form of the offered wage rate equation to be considered here is then

$$\text{WAGE} = f(P,W) \tag{1}$$

where WAGE denotes the offered wage rate paid, P denotes a vector of personal labor supply characteristics, and W denotes a vector of work environment characteristics. Moreover, the vector P is assumed to contain measures of: (1) whether the individual is a union member (uNON), to an individual working 400 hours or less had that individual have chosen to work, for example, full time. An excellent survey of the sample selection problem as it relates hedonic wage and labor supply estimates is contained in the recent paper by Wales and Woodland (1980).

The exact specification of the wage equation used in the present study is shown in Equation (2).

$$\begin{aligned}\text{Ln(RWGH)} = f(&\text{UNON, HVET, FMSZ, HLTH, EDC2, EDC3, TOJ2, WARM,}\\ &\text{JACR, COLD, HUMD, SOXM, TSPM, NOXM, P**2, SOXM**2,}\\ &\text{N**2, CONSTANT).}\end{aligned} \tag{2}$$

In Equation (2), the function f is linear in the parameters and RWGH denotes the real wage. Also , note that the squares of the levels of the three pollution variables are included as regressors in order to allow for possible nonlinearities in the way that air pollution affects the real wage. This equation was estimated by ordinary least squares for both the complete sample of 1395 observations and for selected partitions of this sample constructed on the basis of age (AGEH), race (RACE), sex (SEXH), and occupation (OCCP). In particular, there were three age categories (1729, 3049, 5069), two race categories, (white, nonwhite), two sex categories (male, female), and two occupation categories (white collar, blue collar). The total number of possible partitioned regressions was therefore 24(3x2x2x2). However, not all of these possible regressions were actually estimated because for certain partitions the number of available observations was insufficient.[4]

Before turning to a discussion of the results of these regressions, two additional points should be made regarding the pollution variables. First, as previously indicated, observations on these variables were not available for each of the 669 counties of residence for families (2) whether the individual is a veteran (HVET), (3) the size of the individual's family (FMSZ), (4) the individual's health status (HLTH), (5) the individual's prior educational achievement (EDC2,EDC3), and (6) the length of time the individual has spent on his present job (TOJ2).[7] Next, W contains measures of: (1) mean January and July temperature in the individual's area of residence (COLD, WARM), (2) the job accident rate in the industry where the individual works (JACR), (3) average rainfall in the individual's area of residence, and (4) levels of the air pollutants sulfur dioxide (SOXM), total suspended particulate (TSPM), and nitrogen dioxide (NOXM).

Unfortunately, this formulation may be subject to a specification error of unknown severity resulting from the omission of relevant explanatory variables. While the personal labor supply characteristics are fairly standard for analyses of this type, biased coefficient estimates may result from the exclusion of still other relevant work environment variables. That is, climate, job hazards, and air pollution do not exhaust the list of potential amenities that may affect the offered wage rate. (For good surveys of the role other variables may play, see Brown (1980) and Rosen (1977).) Proximity to recreational opportunities and the amount of local social infrastructure are but two examples of work environment variables that could in principle be measured and included. Also, the more labor market specific variables used by NNK have been excluded from consideration here. Due to budgetary and time constraints, no efforts were made to collect observations on these potentially relevant variables. The variables used to explain variations in the offered wage rate were simply chosen from those that had been collected previously by the Resource and Environmental Economics Laboratory at the University of Wyoming for use on other research projects.

More specifically, the basic data set used to estimate the wage equation consisted of observations drawn from the Panel Study of Income Dynamics (PSID) for the 1971 interview year. In total, there are observations for household heads on variables that can be used to construct a measure of their real wages, together with measures of the variables in the P vector defined previously in Equation (l). The exact definitions of all of these variables as well as their numerical codes used on the PSID tapes are provided in Table

1 entitled Variable Definitions. Table 1 also gives definitions of the variables appearing in the vector W. For the 1971 interview year, the PSID data gives the household's state and county of residence and two digit SIC industry of employment. Consequently, data were collected on COLD, WARM, HUMD, SOXM, NOXM, and TSPM by county and then were matched to the individual observations obtained from the PSID.

For the variables COLD, WARM, AND HUMD, this matching process was quite simple and requires no further elaboration. However, the matching of the air pollution variables to counties should be explained in greater detail. The matching process was begun by listing each of the 669 counties in the 50 states where PSID families lived during 1970. Outdoor air pollution monitoring data existed for at least one of the three measures SOXM, NOXM, AND TSPM for 247 of these counties. In cases, where data from only one monitoring station in the county were available, those data were automatically assigned to all PSID families residing there. On the other hand, where data were available from multiple monitoring stations in the county, data from the single station that had operated for the greatest portion of the nine year period 19671975 were selected. The monitoring stations selected using this rule tended to be at central city locations. Finally, since no pollution data were available for 422 counties (699247), values were assigned to the air quality variables for these counties using one of two procedures for handling missing observations that will be described momentarily.

For the purpose of estimating the hedonic wage equation, the data set was reduced from the roughly 3300 possible observations to 1395 observations after excluding all housholds where: (1) any family member received transfer income, (2) the head's annual hours of working for money was less than 400 hours. The first of these exclusions was made in order to reduce the statistical problem created by families that may be facing nonconvex budget constraints while the second was made in order to eliminate casual workers, who may be out of equilibrium because their asking wage may exceed offered wage, from the sample. Curiously, after making these two exclusions, there were <u>no</u> families remaining in the sample where the head: (1) received income from overtime, bonuses or commissions, or (2) was self employed.

The restricted sample used here is quite similar to that used by Wales and Woodland (1976, 1977, 1978) in their numerous papers on the empirical determinants of labor supply using PSID data. However, by excluding household heads who worked less than 400 hours, the estimates reported in the next section are subject to sample selection bias, a problem dicussed at length by Heckman (1976, 1979). Essentially, Heckman contends that the estimates resulting from such a sample do not apply to the general population. Instead, they apply only to those in the population having the same characteristics of those in the sample. In short, the estimates say little about the wage rate

DISPLAY 1

VARIABLE DEFINITIONS*

A. PECUNIARY VARIABLES

HOURS = (1839) (head's annual hours working for money)

AWGH = (1897) (head's money income from labor)

WAGH = O if HOURS = 0, otherwise WAGH = AWGH/HOURS

BDAL = Index of comparative living costs for a four person family for various areas as published by Bureau of Labor Statistics in the Spring 1967 issue of Three Standards of Living for an Urban Family of Four Persons. The lowest living standard was used. This index is published for the 39 largest SMSAS and by region for other SMSAS.

RWGH = WAGH/BDAL

B. SUPPLY CHARACTERISTIC VARIABLES

HLTH = 1 if (2121) = 1 or 3 or if (2122) = 1 or 3 or both.
= O otherwise (If HLTH = 1, there are limitations on amount or kind of work that the head can do)

UNON = 1 if (2145) = 1, zero otherwise (Head belongs to a labor union if UNON = 1)

EDC1 = 1 if (2197) = 0, 2, 3, or 9 zero otherwise (If EDC1 = 1, head" has completed grades 08 or has trouble reading.)

EDC2 = 1 if (2197) = 3, 4, or 5 zero otherwise (If EDC2 = 1, head has completed grades 912 + possible nonacademic training.)

EDC3 = 1 if (2197) = 6, 7, or 8 zero otherwise (If EDC3 = 1, head has completed at least some college.)

HVET = 1 if (2199) = 1 zero otherwise (If HVET = 1, head is a veteran.)

FMSZ = (1868) (Family size in 1971)

TOJI = 1 if (1987) = 1, 2, or 3 zero otherwise (head's length of time on present job is 3 years or less if TOJI = 1)

TOJ2 = 1 if (1987) = 4, 5, or 6 zero otherwise (head's length of time on present job is longer than 3 years if TOJ2 = 1)

Variable Definitions (Continued)

C. WORK ENVIRONMENT VARIABLES

WARM = Mean annual July temperature in the county of residence in 1970 in F" x 10.0. These data are from the U.S. Bureau of Census, County and City Data Book, 1971.
COLD = Mean annual January temperature in the county of residence in 1970 in F" x 10.0. These data are from U.S. Bureau of Census, County and City Data Book, 1971.
JACR = Number of disabling work injuries in 1970 for each million employee hours worked by 2 and 3 digit SIC code. The data were obtained from Table 163 of Bureau of Labor Statistics, Handbook of Labor Statistics, 1973, Bulletin 1735, U.S. Department of Labor, Washington, DC., USGPO, 1972.
SOXM = Annual 24 hour geometric mean sulfur dioxide micrograms per cubic meter as measured by the Gas Bubbler Pararosaniline Sulfuric Acid Method. These data were obtained from the annual USEPA publication, Air Quality Data Annual Statistics, and refer to a monitoring station in the county of residence for 1970.
HUMD = Mean annual precipitation in inches x 100.0. These data are taken from the U.S. Bureau of Census, County and City Data Book, 1971.
NOXM = Annual 24 hour geometric mean nitrogen dioxide in micrograms per cubic meter as measured by the Salzman Method. These data were obtained from the annual USEPA publication, Air Quality Data Annual Statistics and refer to a monitoring station in the county for residence for 1975.
TSPM = Annual 24 hour geometric mean total suspended particulate in micrograms per cubic meter as measured by the HiVol Gravimetric Method. These data were obtained from the annual USEPA publication, Air Quality Data Annual Statistics and refer to a monitoring station in the county for residence for 1975.
SOXM** = SOXM2
P**2 = TSPM2
N**2 = NOXM2

D. PARTITIONING VARIABLES

AGE = (1972) (head's age in years)
OCCP = 1 if (1984) = 1, 2, 4, or 5 otherwise = O (head is a white collar worker if OCCP = 1 and, a blue collar worker if OCCP = 0)
SEX = 1 if (1943) = 1 otherwise = O (head is male if SEX = 1)
RACE = 1 if (2202) = 1 zero otherwise (If RACE = 1, head is white.)

Variable Definitions (Continued)

E. AUXILIARY VARIABLES

REG1 = 1 if (2284) = 1 otherwise = O (head lives in a northeastern state if REG1 = 1)

REG2 = 1 if (.2284) = 2 otherwise = O (head lives in a northcentral state if REG2 = 1)

REG3 = 1 if (2284) = 3 otherwise = O (head lives in a southern state if REG3 = 1)

REG4 = 1 if (2284) = 4 otherwise = 0 (head lives in a western state if REG4 = 1)

PRX1 = 1 if (2210) = 1 zero otherwise (If PRX1 = 1, head's dwelling unit is within 5 miles of center of city of 50,000 or more.)

PRX2 = 1 if (2210) = 2 zero otherwise (If PRX2 = 1, head's dwelling unit is between 514.9 miles of city center.)

PRX3 = 1 if (2210) = 3 zero otherwise (If PRX3 = 1, head's dwelling unit is between 1529.9 miles of city center.)

PRX4 = 1 if (2210) = 4 zero otherwise (If PRX4 = 1, head's dwelling unit is between 3049.9 miles from city center.)

PRX5 = 1 if (2210) = 5 zero otherwise (If PRX5 = 1, head's dwelling is greater than 50 miles from city center.)

AVGT = Average annual temperature for counties in degrees centigrade for 1970.

*Variable numbers from the PSID tape code book are given for the data collected from the PSID interviews. For the remaining data, no variable numbers are given.

that would be paid in. the PSID data set. In these cases, the missing observations were either replaced by the means of the observed values for the pollutants or estimated using a technique suggested by Dagenais (1973). A brief discussion of the replacement with means method is outlined in Maddala (1977). The Dagenais procedure involves running a regression of each pollution variable on: (1) all remaining (nonpollution) explanatory variables in Equation (2), and (2) relevant auxiliary variables that may be selected and then predicting the values of the missing observations from these regressions.[5] Predicting equations for each of the three pollutants are shown in Tables 21, 22, and 23. As shown in these tables, the auxiliary variables used are dummies relating to the distance of a family's residence from a city center (PRX1, PRX2, PRX3, PRX4, PRX5), the region of the country where the family lives (REG1, REG2, REG3, REG4) and a measure of the average temperature in the family's county of residence (AVGT). Unfortunately, the $R^2$'s for these regressions ranged from .33 for NOXM to .37 for TSPM to .54 for SOXM indicating that their forecasting power may not be particularly high. An alternative to either the replacement with means or the Dagenais' procedures would be to restrict the sample to only those observations where actual measurements were available on all variables, including the pollutants. Even though this restriction reduces the available data set to 112 observations, it was employed in the estimation of one equation for illustrative purposes.[6]

A further problem with the SOXM data is that they were obtained using the Gas Bubbler Pararosaniline Sulfuric Acid Method. This method has been shown to result in estimates of $SO_2$ levels that are biased downward. Mathtech, however, has supplied a conversion equation that corrects for the bias in the original data. That conversion equation is given below.

$$CSOX = 10.625 + 1.97269(SOXM) - 0.10891[SOXM \cdot AVGT] \qquad (3)$$

where CSOX is the converted sulfur dioxide measure. In estimating Equation (2), CSOX was substituted in place of SOXM, and its square, $CSOX^2$ = S**2 was used in place of SOXM**2.

## EMPIRICAL RESULTS

As previously indicated, three basic versions of Equation (2) were estimated where: (1) the restricted sample of 112 observations was employed, (2) the Dagenais procedure was used to construct the pollutants, and (3) the replacement with means procedure was used. All regressions were estimated by OLS.

Table 2 reports the results from estimation with the restricted data set. In this equation, all of the supply characteristic variables are significant at the 1 percent level except HLTH and TOJ2. However, the work environment variables are all insignificant at conventional levels. In fact, the t-statistics on the pollution variables in no case exceed 1.1 in absolute value. Using the replacement with means procedure, the quality of the estimated coefficients improves considerably. These results are shown in Table 3. With the increase in the number of observations employed from 112 to 1395, all of the supply characteristic variables turn out to be significant at the 1 percent level and.have the correct sign. Differences in data sets and in equation specifications make it difficult to directly compare these results to those obtained in previous studies. Nevertheless, their general pattern of the estimates presented in Table 3 corresponds closely to those obtained by other investigators.

The estimates of the coefficients on the work environment variables also tend to be more highly significant and are more plausibly signed than in the case where the restricted sample of 112 observations is used. Also, they are generally consistent with the findings of other investigators. As indicated in Table 3, the variables WARM and COLD enter with a significant negative sign. In the case of WARM, the negative sign indicates that the individuals in the sample are willing to accept a lower wage in order to live in an area with hot summers. That same qualitative result has been obtained by Rosen (1979) using individual data from the Current Population Survey together with SMSA specific attributes and by Hoch (1977) and Cropper (1979) using aggregate SMSA data exclusively. On the other hand, the negative sign on COLD suggests that individuals must be paid a premium to live in areas where mean January temperatures are low and winter weather is probably severe. Of the three studies just mentioned, only the one by Hoch employs a similar variable. The coefficient on “winter temperature” is positive in his regressions on Samples I and II and negative in his regression on Sample III (see Hoch's Table 5, p. 39) .

Next, the coefficient on JACR is positive and significant supporting Viscusi's (1978) result that employers must pay a premium in order to induce workers to accept jobs where the probability of accidents is higher. Also , this result is consistent with the findings of other investigators who measured other dimensions of working conditions. For example, Lucas (1977), Hammermesh (1977), and Thaler and Rosen (1975) consider the effect of wages of variables including: (1) a generalized measure of poor working conditions, (2) the presence of hazardous materials and/or equipment, and (3) deaths per 1,000 man years of work. All three of these variables have been found to be positively and significantly related to similar dependent variables to the one used in the present study.

With respect to the HUMD variable, Table 3 shows that its coefficient is negative but ‘statistically insignificant at the 5 percent level. Although this negative sign is intuitively implausible, that same result was obtained in Hoch's regressions on each of his three samples. Rosen, however, obtains the more appealing result that increases in precipitation are positively associated with real wages. The precipitation variable that Rosen uses, which is defined as number of rainy days, was always positive and usually statistically significant in each of 29 different equation specifications (see Rosen's Table 3.3, p. 94).

The pollution variables do not perform quite as well as the other variables in the equation. Both the linear and quadratic terms for CSOX and for NOXM are statistically insignificant at the 5 percent level. The result for CSOX conflicts with those of Cropper (1979). In her regression for all earners and in four of her eight occupation specific regressions, a measure of $SO_2$ turned out to be positively and significantly related to median earnings of males who were employed full time. However, in the Cropper study $SO_2$ was the only pollution measure used and, therefore, this variable could also be proxying the effects of other pollutants. Rosen's results show that this conjecture is a real possibility. His $SO_2$ measure occasionally has the right sign, but is more frequently negative and significant. Particulate, on the other hand, exhibit superior performance in Rosen's equation. This variable was positive in each of the 32 cases where it was used and had a tstatistic exceeding 2 in 27 cases (again, see Rosen's Table 3.3, p.94). The results on the TSPM variable used in the present study compares favorably with the findings of Rosen. As Table 3 shows, the linear TSPM term has a positive and statistically significant coefficient and the quadratic TSPM term has a smaller negative but significant coefficient.

The elasticity of the real wage with respect to a change in TSPM can be computed from the estimates presented in Table 3 according to

$$e_{TSPM} = \frac{\partial RWGH}{\partial TSPM} \frac{TSPM}{RWGH} = \alpha'' TSPM + 2\beta'' TSPM^2 \qquad (4)$$

where $e_{TSPM}$ denotes the elasticity, a denotes the estimated coefficient on the linear term and β denotes the coefficient on the quadratic term. Evaluated at the mean of the observed values for TSPM, $e_{TSPM}$ = 0.0367, evaluated at the national primary standard, $e_{TSPM}$ = .1322, and evaluated at the national secondary standard, $e_{TSPM}$ = .2005. The mean of the actually observed values of TSPM = 96.56 and the national primary and secondary standards for TSPM are shown in Table 24. The comparatively high value for the mean of TSPM can be attributed to a relatively small number of counties in the data set where total suspended particulate was considerably in excess of 100. In any case, these results suggest that in the neighborhood of the national air quality standards benefits from reducing TSP concentrations are likely to exist.

Illustrative calculations of benefits of national pollution abatement programs are presented for two SMSAs, Denver and Cleveland. These calculations are derived from the pooled regression estimates in Table

In particular:

(i) SMSA specific means for the variables EDC2, EDC3, HVET, and FMSZ were obtained from the 1970 U.S. Census 1 in 100 public use sample tapes and substituted into the equation reported.

(ii) SMSA specific averages for the variables WARM, COLD, and HUMD were obtained from other sources and substituted into the equation reported.

(iii) For the remaining nonpollution variables, UNON, HLTH, TOJ2, and JACR, the sample means reported in Table 22 were substituted into the equation reported. This procedure was used because of the difficulties in obtaining meaningful SMSA specific means for these variables.

These means, which are reported in Table 26, were then multiplied by their respective coefficients in order to obtain a predicted wage exclusive of pollution effects.

For the pollution variables, it was assumed that neither community would have air pollution levels higher than the primary standards for SO , $NO_2$ and TSP by 1985 and that the secondary standards for all three pollutants would be met by 1987. In cases where current (1978) pollution concentrations are lower than the secondary standards, those current concentrations were assumed to prevail throughout the forseeable future. As previously indicated, Table 27 reports the national primary and secondary standards legislated to take effect in 1985 and Table 28 reports 1978 pollution concentrations for Denver and Cleveland.

In Denver, for example, the change in the predicted RWGH associated with a reduction in total suspended particulate concentrations was obtained holding constant the values of the other pollution and nonpollution variables. The values for the remaining pollution variables were held constant because Denver is already meeting the national secondary standards for them. Also, the values of the nonpollution variables were assumed to remain unchanged over time. Projected benefits were then obtained by multiplying the change in the hourly real wage by annual hours of full time work and then multiplying this result by an estimate of the number of affected household heads in each SMSA.

Annual hours of full time work were assumed to be 2000 and the 1 in 100 Census Bureau public use sample indicated that there were approximately 382,700 household heads in Cleveland and 218,100 household heads in Denver with the hours of work and employment characteristics required for inclusion in the sample used to make the pooled regression estimates.

Annual benefit estimates from pollution abatement in the two cities are positive according to the calculations made here. For Denver, meeting the national secondary standards for TSP results in a reduction in the offered real wage, from $4.1758/hr. to $3.9626/hr. Multiplying this difference of $.2136/hr. by the number of persons affected times 2000 hours yields an estimated annual benefit for Denver of $92,968,935. A similar calculation for Cleveland reveals that meeting the national secondary air quality standards causes the real wage to fall from $3.8756/hr. to $3.7693/hr. implying a benefit of $81,360,489. Note that benefits per <u>household head</u> in the two cities are $426.35 for Denver and $212.60 for Cleveland. Simple calculations using the estimates in Table 3 and the mean values in Table 26 show that reductions in TSP levels would be responsible for all of these estimated benefits. The larger value for benefits for all of these estimated benefits per person in Denver arises because greater reductions must be achieved as compared with Cleveland, in order to achieve the national secondary standards.

Finally, the results from estimating Equation (2) using the Dagenais procedure to construct the missing observations on the pollution variables are reported in Tables 4 through 20.[7] Tables 4 through 19 contain various partitions of Equation (2) based upon age, race, and sex and Table 20 contains the pooled sample regression. The coefficients on the supply characteristic variables reported in Table 20 are very similar to those reported in Table 3. However, both the linear and quadratic terms for all three pollutants enter the pooled regression insignificantly at the 5 percent level using a twotailed test. In the partitioned regression equations, the[8] air pollution variables are seldom significantly different from zero either. More specifically, there are five of these regressions where one of the pollution variables entered significantly. These are: (1) the Male, White, White Collar Worker, Age 5069 partition (TSPM), (2) the Male, White, Blue Collar Worker, Age 3049 partition (TSPM), (3) the Male, White, Blue Collar Worker, Age 1769 partition (CSOX), (4) the Male, NonWhite, Blue Collar Worker, Age 3049 partition (CSOX), (5) the Female, White, White Collar Worker, Age 1769 partition (TSPM). Neither the linear nor the quadratic term on NOXM was ever significantly different from zero at the 5 percent level. In the five cases where a pollution variable was significant, the elasticity of the real wage with respect to a change in the pollution was computed using the method shown in Equation (4). All of these elasticities were evaluated at the grand mean (computed over all 1395 observations) of the pollution variables. These means, together with the means and standard deviations of all variables used in this analysis are shown in Table 25. Finally, the results of the elasticity calculations are presented beneath the coefficient estimates for the equations to which they pertain. As indicated there, three of the calculated elasticities are positive while two are negative.

The relatively weaker performance of the pollution variables in the equations estimated using the Dagenais procedure can perhaps be attributed to several factors. First, although Dagenais shows that his method produces consistent prediction of the missing observations, this asymptotic property may say little about the finite sample properties of such a procedure, particularly when a large fraction of the observations are missing. Table 29 shows how this missing observations problem relates to each of the 16 partitional equations estimated. In particular, this table presents the number of observations for each partition for which actual pollution data were available. As can be seen, four of these partitions had no observations where data on all three pollutants were available. Second, the consistency of Dagenais' method depends upon the use of a generalized least squares procedure to estimate the hedonic wage relation that requires the solution of a set of simultaneous, nonlinear equations. Because of computational difficulties, OLS was used instead. In this setting, it is not clear what statistical properties can be claimed for the Dagenais approach. Two other reasons for weak performance, which are common to the replacement with means procedure can also be offered: (1) observations that do exist on the air pollutants may be measured with so much error that they provide a great deal of misinformation, (2) after adjusting for the other factors included in each regression, air pollution, even if measured perfectly, may not be an important determinant of wages paid.

Illustrative benefit calculations were also made for Denver and Cleveland using the estimtaes presented in Table 20. The procedure for making these calculations was the same as that described previously. For Denver, meeting the national secondary standards for TSP results in a reduction in the offered wage from $4.3545/hour to $4.0490/hour implying that annual benefits per household head are $611 and total benefits are $133,198,000. For Cleveland, on the other hand, meeting the national secondary air quality standards causes the real wage to fall from $3.3251/hour to $3.2336/hour so that annual benefits per household head are $183 and total benefits are $70,034,100.